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Optimal Placement of DG for Loss Reduction and Voltage Sag Mitigation in Radial Distribution Systems using ABC Algorithm

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Abstract — **This paper presents the need to operate the power system economically and with optimum levels of voltages has further led to an increase in interest in Distributed Generation. In order to reduce the power losses and to improve the voltage in the distribution system, distributed generators (DGs) are connected to load bus. To reduce the total power losses in the system, the most important process is to identify the proper location for fixing and sizing of DGs. It presents a new methodology using a new population based meta heuristic approach namely Artificial Bee Colony algorithm(ABC) for the placement of Distributed Generators(DG) in the radial distribution systems to reduce the real power losses and to improve the voltage profile, voltage sag mitigation. The power loss reduction is important factor for utility companies because it is directly proportional to the company benefits in a competitive electricity market, while reaching the better power quality standards is too important as it has vital effect on customer orientation. In this paper an ABC algorithm is developed to gain these goals all together. In order to evaluate sag mitigation capability of the proposed algorithm, voltage in voltage sensitive buses is investigated. An existing 20KV network has been chosen as test network and results are compared with the proposed method in the radial distribution system.**

Index Terms—**Distributed generation, optimal DG placement, Power loss Reduction, Artificial Bee Colony Algorithm, Voltage Sag mitigation.**

I. Introduction

Distributed generation unlike centralized electrical generation aims to generate electrical energy on small scale as near as possible to load centers, which provide an incremental capacity to power system. In the deregulated power market, concerns about the environment as well as economic issues have led increased interest in distributed generations. The emergence of new technological alternatives (photovoltaic systems, wind power, cogeneration, etc.) allows generating part of the required energy closer to the point of use, improving quality levels and minimizing the investments costs associated with of transmission and distribution systems. With electricity market undergoing tremendous transformation, more price instability in the market, ageing infrastructure and changing regulatory environments are demanding users and electric utilities to exploit benefits of DG [1, 2].

DG applications are growing due to environmental and economic issues, technological improvements, and privatization of power systems. DG application, however, has positive and negative side effects for public industries and consumers [3]. DG makes use of the latest modern technology which is efficient, reliable, and simple enough so that it can compete with traditional large generators in some areas [4].

In the literature, Single DG Placement algorithm has been applied to DG placement and ABC algorithm for the Sizing of DG in the radial distribution systems [5]. The ABC algorithm is a new population based Meta heuristic approach inspired by intelligent foraging behavior of honeybee swarm. The advantage of ABC algorithm is that it does not require external parameters such as cross over rate and mutation rate as in case of genetic algorithm and differential evolution. The other advantage is that the global search ability is implemented by introducing neighborhood source production mechanism which is similar to mutation process. In this paper, locations of distributed generators are identified by single DG placement method [6] and ABC algorithm which takes the number and location of DGs as input has been developed to determine the optimal size(s) of DG to minimize real power losses in distribution systems. The advantages of relieving ABC method from determination of locations of DGs are improved convergence characteristics and less computation time. Voltage and thermal constraints are considered [7].

The conventional distribution grids are commonly fed unidirectional, a fault or starting a large size motor in one bus of the grid can cause voltage sag in buses in vicinity [8]. DG supports voltage in connection point [9] and this efficiency is highly dependent on the size and location of DG unit, so optimal sizing and location of DG can givethe opportunity to benefit this potential capacity to mitigate voltage sags, particularly in buses with sensitiveloads.

The proposed (ABC) based approach is tested on a practical 32-bus radial distribution system and the scenarios yields efficiency in improvement of voltage profile and reduction of voltage sags and power losses, it also permits an increase in power transfer capacity and maximum loading.

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II. Losses In A Distribution System

The total I^2R loss (P_{lt}) in a distribution system having n number of branches is given by:

$$P_{lt} = \sum_{i=1}^{n} I_{ti}^{2} R_i \rightarrow (1)$$

Here I_{ti} is the magnitude of the branch current and R_i is the resistance of the i^{th} branch respectively. The branch current can be obtained from the load flow solution. The branch current has two components, active component (I_{ai}) and reactive component (I_{ri}). The loss associated with the active and reactive components of branch currents can be written as

$$P_{la} = \sum_{i=1}^{n} I_{ai}^{2} R_i \rightarrow (2)$$

$$P_{lr} = \sum_{i=1}^{n} I_{ri}^{2} R_i \rightarrow (3)$$

Note that for a given configuration of a single-source radial network, the loss P_{la} associated with the active component of branch currents cannot be minimized because all active power must be supplied by the source at the root bus. However by placing DGs, the active components of branch currents are compensated and losses due to active components of branch currents are reduced. This paper presents a method that minimizes the loss due to the active component of the branch current by optimally placing the DGs and thereby reduces the total loss in the distribution system [10].

III. Single Dg Placement Algorithm

This algorithm determines the optimal size and location of DG units that should be placed in the system to minimize loss. First optimum sizes of DG units for all nodes are determined for base case and best one is chosen based on the maximum loss saving. This process is repeated if multiple DG locations are required by modifying the base system by inserting a DG unit into the system one-by-one [11].

A. Methodology

Assume that a single-source radial distribution system with n branches and a DG is to be placed at bus m and r is a set of branches connected between the source and bus m. The DG produces active current I_{dg}, and for a radial network it changes only the active component of current of branch set r. The currents of other branches are unaffected. Thus new active current I_{ai}^{new} of the i_{th} branch is given by

$$I_{ai}^{new} = I_{ai} + D_i I_{dg} \rightarrow (4)$$

Where D_i=1; if branch i $\in$ r
=0; otherwise

The loss P_{la}^{dg} associated with the active component of branch currents in new system (when DG is connected) is given by

$$P_{la}^{dg} = \sum_{i=1}^{n} (I_{ai} + D_i I_{dg})^2 R_i \rightarrow (5)$$

The saving S is the difference between equation (2) and (5) and is given by

$$S = P_{la} - P_{la}^{dg}$$
$$= -\sum_{i=1}^{n} (2 D_i I_{ai} I_{dg} + (D_i I_{dg})^2) R_i \rightarrow (6)$$

The DG current I_{dg} that provides maximum saving can be obtained from

$$\frac{\partial S}{\partial I_{dg}} = -2\sum_{i=1}^{n} (D_i I_{ai} + D_i I_{dg}) R_i = 0 \rightarrow (7)$$

The DG current for maximum saving is

$$I_{dg} = -\frac{\sum_{i=1}^{n} I_{ai} D_i Ri}{\sum_{i=1}^{n} D_i R_i} = -\frac{\sum_{i\in r} I_{ai} R_i}{\sum_{i\in r} R_i} \rightarrow (8)$$

The corresponding DG size is $P_{dg}=V_m I_{dg} \rightarrow (9)$

Where V_m is the voltage magnitude of bus-m.

The optimum size of DG at each bus is determined using equation (9).Then saving for each DG is determined using equation (6).The DG with highest saving is candidate location for single DG placement. When the candidate bus is identified and DG is placed, the process is repeated to identify subsequent buses for DG placement [12].

B. Algorithm for Single DG Placement

Step 1: Conduct load flow analysis for the original system.
Step 2: Calculate I_{dg} and DG size using equations (8)&(9) for buses i=2…n.
Step 3: Determine saving using equation 6, for buses i=2…n.
Step 4: Identify the maximum saving and the corresponding DG size.
Step5: The corresponding bus is candidate bus where DG can be placed. Modify the active load at this bus and conduct the load flow again.
Step 6: Check whether the saving obtain is more than 1kW. If yes, go to step 2. Otherwise, go to next step.
Step 7: print all the candidate locations to place DG sources and the sizes.

Since the DGs are added to the system one by one, the sizes obtained by single DG placement algorithm are local optima not global optimum solution. The global optimal solution is obtained if multiple DGs are simultaneously placed in the system by using ABC algorithm. This method is explained in next section.

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IV. Artificial Bee Colony Algorithm (Abc)

Artificial Bee Colony (ABC) is one of the most recently defined algorithms by Dervis Karaboga in 2005, motivated by the intelligent behavior of honeybees. ABC as an optimization tool provides a population based search procedure in which individuals called food positions are modified by the artificial bees with time and the bee's aim is to discover the places of food sources with high nectar amount and finally the one with the highest nectar. In this algorithm [11, 12], the colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts. First half of the colony consists of the employed artificial bees and the second half includes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source has been abandoned becomes a scout [13]. Thus, ABC system combines local search carried out by employed and onlooker bees, and global search managed by onlookers and scouts, attempting to balance exploration and exploitation process [14].

The ABC algorithm creates a randomly distributed initial population of solutions ($f = 1,2,\ldots..,T_{nf}$), where 'f' signifies the size of population and 'T_{nf}' is the number of employed bees. Each solution x_f is a D-dimensional vector, where D is the number of parameters to be optimized. The position of a food-source, in the ABC algorithm, represents a possible solution to the optimization problem, and the nectar amount of a food source corresponds to the quality (fitness value) of the associated solution. After initialization, the population of the positions (solutions) is subjected to repeated cycles of the search processes for the employed, onlooker, and scout bees (cycle = 1, 2, …, *MCN*), where *MCN* is the maximum cycle number of the search process. Then, an employed bee modifies the position (solution) in her memory depending on the local information (visual information) and tests the nectar amount (fitness value) of the new position (modified solution). If the nectar amount of the new one is higher than that of the previous one, the bee memorizes the new position and forgets the old one. Otherwise, she keeps the position of the previous one in her memory. After all employed bees have completed the search process they share the nectar information of the food sources and their position information with the onlooker bees waiting in the dance area. An onlooker bee evaluates the nectar information taken from all employed bees and chooses a food source with a probability related to its nectar amount. The same procedure of position modification and selection criterion used by the employed bees is applied to onlooker bees. The greedy-selection process is suitable for unconstrained optimization problems. The probability of selecting a foodsource P_f by onlooker bees is calculated as follows:

$$P_f = \frac{fitness}{\sum_{f=1}^{T_{nf}} fitness_f} \rightarrow (10)$$

Where $fitness_f$ is the fitness value of a solution f, and T_{nf} is the total number of food-source positions (solutions) or, in other words, half of the colony size. Clearly, resulting from using (10), a good food source (solution) will attract more onlooker bees than a bad one. Subsequent to onlookers selecting their preferred food-source, they produce a neighbor food-source position $f+1$ to the selected one f, and compare the nectar amount (fitness value) of that neighbor $f+1$ position with the old position. The same selection criterion used by the employed bees is applied to onlooker bees as well. This sequence is repeated until all onlookers are distributed. Furthermore, if a solution f does not improve for a specified number of times (limit), the employed bee associated with this solution abandons it, and she becomes a scout and searches for a new random food-source position. Once the new position is determined, another ABC algorithm (*MCN*) cycle starts. The same procedures are repeated until the stopping criteria are met. In order to determine a neighboring food-source position (solution) to the old one in memory, the ABC algorithm alters one randomly chosen parameter and keeps the remaining parameters unchanged. In other words, by adding to the current chosen parameter value the product of the uniform variant [-1, 1] and the difference between the chosen parameter value and other "random" solution parameter value, the neighbor food-source position is created. The following expression verifies that

$$x_{fg}^{new} = x_{fg}^{old} + u(x_{fg}^{old} - x_{mg}) \rightarrow (11)$$

Where $m \neq f$ and both are $\in \{1,2,\ldots.T_{nf}\}$. The multiplier u is a random number between [-1, 1] and $g \in \{1,2,\ldots D\}$. In other words, x_{fg} is the g^{th} parameter of a solution x_f that was selected to be modified. When the food-source position has been abandoned, the employed bee associated with it becomes a scout. The scout produces a completely new food source position as follows:

$$x_{fg}^{(new)} = \min(x_{fg}) + u\left[\max(x_{fg}) - \min(x_{fg})\right] \rightarrow (12)$$

Where (12) applies to all g parameters and u is a random number between [-1, 1]. If a parameter value produced using (11) and/or (12) exceeds its predetermined limit, the parameter can be set to an acceptable value. In this paper, the value of the parameter exceeding its limit is forced to the nearest (discrete) boundary limit value associated with it. Furthermore, the random multiplier number u is set to be between [0, 1] instead of [-1, 1].

Thus, the ABC algorithm has the following control parameters: 1) the colony size (CS), that consists of employed bees T_{nf} plus onlooker bees T_{nf}; 2) the limit value, which is the number of trials for a food-source position (solution) to be abandoned; and 3) the maximum cycle number *MCN* .

The proposed ABC algorithm for finding size of DG at selected location to minimize the real power loss is as follows:
Step-1: Initialize the food-source positions x_f (solutions population), where $f = 1,2,\ldots..,T_{nf}$. The x_f solution form is as follows.

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Step-2: Calculate the nectar amount of the population by means of their fitness values using

$$Fitness = \frac{1}{1 + powerloss} \rightarrow (13)$$

Step-3: Produce neighbor solutions for the employed bees by using (11) and evaluate them as indicated by Step 2.
Step-4: Apply the greedy selection process.
Step-5: If all onlooker bees are distributed, go to Step 9. Otherwise, go to the next step.
Step-6: Calculate the probability values P_f for the solutions x_f using (10)
Step-7: Produce neighbor solutions for the selected onlooker bee, depending on the value, using (8) and evaluate them as Step 2 indicates.
Step-8: Follow Step 4.
Step-9: Determine the abandoned solution for the scout bees, if it exists, and replace it with a completely new solution using (12) and evaluate them as indicated in Step 2.
Step-10: Memorize the best solution attained so far.
Step-11: If cycle = MCN, stop and print result. Otherwise follow Step 3.

V. Voltage Sag Mitigation

The Proposed approach deals with voltage sag propagation mitigation. This takes into account the *number of buses* that experience voltage sag. (14) Shows the proposed function to minimize the voltage sag and thereby increasing the voltage amplitudes in radial distribution system [15].

$$V_{sp} = \omega_1 V_l + \omega_2 V_m + \omega_3 V_h \rightarrow (14)$$

In which V_l is the number of buses with voltage amplitude drop below 0.1 p.u, V_m is the number of buses with voltage amplitude between 0.4 p.u and 0.7 p.u and finally V_h is the number of buses with voltage amplitude between 0.7 p.u and 0.9 p.u during voltage sag occurrence. Weighting coefficients are defined as $\omega_1 = 0.1$, $\omega_2 = 0.3$ and $\omega_3 = 0.6$ to magnify voltage support in more ill-conditioned buses.

VI. Illustrative Example

An existing 20KV network which is modeled with 32 buses is studied. This medium voltage feeder which is located in south Khorasan province in Iran has severe voltage problems especially in peak load hours and in end feeder areas. Figure 1 shows single line diagram of this network.

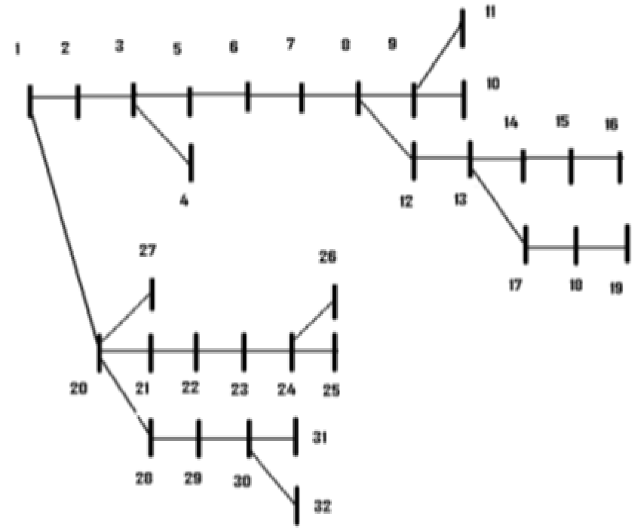

Fig. 1 Single Line Diagram of the Test Network

Table I: The Load Data of 32-Bus System

Bus No	P_L KW	Q_L KVAr	Load KVA	Sen. Node	Rec. Node	R Ω	X_L Ω
1	-	-	-				
2	360	63	425	1	2	1.32	0.48
3	0	0	0	2	3	1.56	0.56
4	170	30	200	3	4	0.78	0.28
5	445	78	525	3	5	1.4	0.51
6	467	82	550	5	6	3.3	1.2
7	85	15	100	6	7	7.8	2.8
8	-	-	-	7	8	3.4	1.2
9	573	101	675	8	9	6.8	2.4
10	85	15	100	9	10	12	4.6
11	42	7	50	9	11	7	2.8
12	85	15	100	8	12	4.6	1.7
13	85	15	100	12	13	2.9	1
14	85	15	100	13	14	12.5	4.5
15	63	11	75	14	15	11.7	4.2
16	488	86	575	15	16	3.1	1.1
17	148	26	175	13	17	5.4	1.9
18	191	33	225	17	18	4.6	1.7
19	127	22	150	18	19	6.8	2.4
20	-	-	-	1	20	4.4	1.6
21	190	33	225	20	21	4.4	1.6
22	127	22	150	21	22	11.2	4
23	297	52	350	22	23	7.8	2.8
24	-	-	-	23	24	7.8	2.8
25	467	82	550	24	25	3.9	1.4
26	276	48	325	24	26	5.1	1.8
27	85	15	100	20	27	5.8	2.8
28	430	75	505	20	28	11.7	4.2
29	191	33	225	28	29	5.08	1.8
30	-	-	-	29	30	4.4	1.6
31	85	15	100	30	31	9.8	1.3
32	63	11	75	30	32	5.6	2

VII. Results And Analysis

First load flow is conducted for 32-bus test system. The power loss due to active component of current is 1015.9 kW and power loss due to reactive component of the current is 42.5752 kW. A program is written in "MATLAB" to implement single DG placement algorithm. For the first iteration the maximum saving is occurring at bus 8. The candidate location for DG is bus 8 with a loss saving of 475.8859 kW.The optimum size of DG at bus 8 is 2.6656 MW. By assuming 2.6656 MW DG is connected at bus 8 of base system and is considered as base case. Now the candidate location is bus with 0.4908 MW size and the loss saving is 120.6142 KW. This process is repeated till the loss saving is insignificant. The results are shown in Table 2.

The candidate locations for DG placement are taken from single DG placement algorithm i.e. 8,30,29,27. With these locations, sizes of DGs corresponding to global solution are

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TABLE II: SINGLE DG PLACEMENT RESULTS

Iteration No	Bus No	DG Size (MW)	Saving (KW)
1	8	2.6656	502.0992
2	30	0.4908	120.6142
3	29	0.4383	87.0670
4	27	0.4405	76.2773

determined by using ABC Algorithm described in section IV.

TABLE III: RESULTS OF 32-BUS SYSTEM

Case	Bus Locations	DG Size (KW)	Total Size (MW)	Losses Before DG installation (KW)	Losses After DG Installation (KW)	Savings (KW)
I	8	2.6656	2.6656	1058.4	462.6422	595.7578
II	8	0.2188	0.7096		378.6582	679.7418
	30	0.4908				
III	8	0.1825	1.0432		336.2174	722.1826
	30	0.4224				
	29	0.4383				
IV	8	0.1518	1.3353		311.5574	746.8426
	30	0.3594				
	29	0.3836				
	27	0.4405				

The sizes of DGs are dependent on the number of DG locations. Generally it is not possible to install many DGs in a given radial system. Here there are four cases are considered. In case I only one DG installation is assumed. In case II two DGs , in case III three DGS and in the last case four DGs are assumed to be installed.

DG sizes in the four optimal locations, total real power losses before and after DG installation for four cases are given in Table 3.Due to the installation of the three DG's at the determined locations with the corresponding determined at sizes, the totalreal power loss of the system is reduced from 1015.9KW to 283.658KW with a maximum saving of 732.242KW. The results are shown in table 5.

Similarly due to the introduction of DG in to the system the voltage profile has been improved which is represented in the above table 4.

VIII. CONCLUSION

In this paper, a single DG placement method is proposed to find the optimal locations of DG and Artificial Bee Colony (ABC) algorithm is proposed to find the optimal sizes of DGs for maximum loss reduction of radial distribution systems is presented. Due to high employment of voltage sensitive equipment's, voltage support in sensitive loads are a great concern for utility companies. Beside network operation cost is directly affected by power loss. In this paper a long and highly loaded 20KV feeder has been under investigation to find optimal location and sizing for DG units to support 30% of the feeder load. This DG penetration level is reasonable due to economic considerations. The presence of two highly voltage sensitive loads in this feeder have made network expansion planners think of voltage sag mitigation and voltage support in these buses. Beside, because of ill-conditioned network, Loss reduction and voltage profile improvement have been of great concern as well. Objective functions with different approaches have been defined and different scenarios were investigated. Results show significant reduction in power loss in addition to voltage profile improvement. Capability of proposed method for voltage sag mitigation in sensitive buses has been also investigated and was proved to be within acceptable limits.

TABLE IV: RESULTS FOR VOLTAGE PROFILE BEFORE AND AFTER DG INSTALLATION

Bus No	Voltages Before DG Installation	Voltages After DG Installation	Voltages After Voltage sag mitigation
1	1.0000	1.0000	1.0000
2	0.9768	0.9875	0.9924
3	0.9601	0.9833	0.9882
4	0.9601	0.9833	0.9882
5	0.9464	0.9808	0.9857
6	0.9159	0.9765	0.9815
7	0.8539	0.9759	0.9809
8	0.8319	0.9801	0.9851
9	0.8169	1.0128	1.0176
10	0.7938	0.9943	0.9992
11	0.8150	1.0112	1.0161
12	0.8134	0.9646	0.9697
13	0.8022	0.9553	0.9604
14	0.7923	0.9471	0.9522
15	0.7865	0.9422	0.9474
16	0.7858	0.9416	0.9468
17	0.7870	0.9427	0.9479
18	0.7817	0.9382	0.9435
19	0.7773	0.9345	0.9398
20	0.9469	0.9580	0.9791
21	0.9321	0.9434	0.9650
22	0.8947	0.9065	0.9290
23	0.8730	0.8852	0.9082
24	0.8544	0.8668	0.8903
25	0.8544	0.8668	0.8903
26	0.8469	0.8594	0.8832
27	0.9423	0.9534	0.9747
28	0.9198	0.9312	0.9943
29	0.9093	0.9209	0.9964
30	0.9058	0.9174	1.0033
31	0.9058	0.9174	1.0151
32	0.9044	0.9160	1.0020

TABLE V: RESULTS FOR REAL POWER LOSS BEFORE AND AFTER DG INSTALLATION

	Losses Before DG Installation (KW)	Losses After DG installation (KW)
Real Power Loss	1015.9	283.658

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